Radial and Solar Cycle Variations in the Solar Wind Phase Fluctuation Spectral Index as Determined From Voyager 1978 Solar Conjunction Data

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Of current interest is the value of and possible variations in the solar wind phase fluctuation spectral index. This article presents columnar spectral index information that has been extracted from a sizable volume of Voyager 1978 solar conjunction doppler phase fluctuation data. The Voyager 1978 results, when compared to similar information derived from the 1976 Helios and Viking Solar Conjunctions, lead to the following inferences: (1) there has been a significant change in the spectral index from 1976 to 1978; (2) there is continuing evidence that favors a slight (positive) correlation between the spectral index and the solar (sunspot) cycle; (3) there is little or no evidence in support of a radial variation of the spectral index.

I. Introduction

During the last decade, much work has been performed to determine the form of the solar wind fluctuation spectrum. During this period, and through analysis of both spacecraft in-situ and radio scattering measurements, it has become evident that the form of the fluctuation spectrum is best described as power-law with fluctuation frequency (ν); see, for example, Intriligator, et al., Ref. 1; Goldstein, et al., Ref. 2; Unti, et al., Ref. 3; Woo, et al., Ref. 4; and Chang, Ref. 5. It is currently of considerable interest to determine the numerical value of the (power-law) spectral index[1], and, additionally, any possible functional dependencies of the spectral index on:

(1) Fluctuation frequency regime.

(2) Radial distance.

(3) Solar cycle variations.

Recently, Coles, et al., Ref. 6, have determined spectral index variations with both radial distance and fluctuation frequency regime through analysis of intensity scintillation of incoherent radio sources. In contrast to these results, Berman, (Ref. 7), analyzing Viking Doppler phase fluctuation data generated by the Deep Space Network (DSN) during the 1976 solar conjunction, found no indication of a radial dependence of the spectral index. It should be noted, however, that these

[1] The term "spectral index" will specifically imply the *columnar* (two-dimensional) spectral index.

(differing) results were obtained in different regimes of the fluctuation spectrum; whereas the scintillation results from Ref. 6 are for fluctuation frequencies (ν) greater than 0.1 Hz, the Doppler results are for fluctuation frequencies less than 0.03 Hz.

To date, little work has been performed on determining possible variations of the spectral index with solar cycle. Berman recently noted (Ref. 8) that, based on the totality of spectral index measurements to date (1977), the (available) evidence pointed to, at most, only a slight variation of spectral index with solar cycle. Further, Ref. 8 indicated that if indeed correlation did exist between the spectral index and solar cycle, the correlation appeared to be *positive*, i.e., the fluctuation spectrum appeared to be *steeper* during solar cycle (sunspot) maximum.

This article presents the results of extracting spectral index information from a large volume of Doppler phase fluctuation data generated by the DSN during the Voyager 1978 solar conjunction. Analysis of these data indicates:

(1) There was a significant increase in the spectral index between solar cycle minimum (1976) and (near) solar cycle maximum (1978).

(2) There is continued evidence for slight (positive) correlation between the spectral index and the Solar Cycle.

(3) There is little evidence of a significant variation of the spectral index with radial distance (at least in the low frequency portion of the fluctuation spectrum).

II. Helios and Viking Spectral Index Data During 1976

Berman (Refs. 7 and 9) has analyzed a large volume of Doppler phase fluctuation data generated by the DSN during the 1976 solar conjunctions of Helios and Viking. Analysis of the spectral index information derived from the Helios and Viking data yielded the following conclusions (Ref. 7):

(1) The mean value of the spectral index during 1976 was 2.42.

(2) There was little or no indication of a spectral index radial dependence.

Figure 1 (from Ref. 7) presents the spectral index, as computed from Viking Doppler phase fluctuation data, versus Sun-Earth-probe (SEP) angle. The absence of any significant spectral index radial dependence is obvious from inspection of Fig. 1.

III. Voyager Spectral Index Data During 1978

In 1977, the DSN implemented a new capability to allow the convenient extraction of spectral index information from Doppler phase fluctuation data; this capability is described in detail in Refs. 7 and 10. Using this new capability, spectral index information has been computed from Voyager 1 Doppler phase fluctuation data. Very briefly, the spectral index extraction process is predicated on the relationship (Ref. 10):

$$\phi^2 \propto \nu^{-K_0+1}$$

where:

ϕ = rms Doppler phase fluctuation

ν = fluctuation frequency

K_0 = spectral index

The Voyager 1 two-way Doppler phase fluctuation data were analyzed during the periods June 17, 1978, to July 7, 1978, and July 20, 1978, to August 8, 1978. During these periods, the SEP varied between 3.6 deg and 17.9 deg. The fluctuation frequency (ν) range over which the spectral index was computed for the Voyager 1 data was:

$$2.8 \times 10^{-4} \text{ Hz} < \nu < 2.8 \times 10^{-3} \text{ Hz}$$

The spectral index information determined from the Voyager 1 Doppler phase fluctuation data is presented in Figs. 2 and 3. Figure 2 presents the spectral index vs day of year (DOY), while Fig. 3 presents the spectral index vs SEP.

The mean value of the spectral index as computed from the Voyager 1 data is $K_0 = 2.67$, as compared to a spectral index mean value of $K_0 = 2.42$ as determined from the Viking and Helios data. This difference is considered statistically significant in light of the large volume of data analyzed in both cases. For the 1976 mean spectral index, 42 pass average (~3 hours of Doppler data) spectral index measurements were available, while in the case of the 1978 mean spectral index, 71 pass average measurements were utilized. Since 1976 constituted solar cycle 20 minimum, and mid-1978 is near (according to Sunspot number) solar cycle 21 maximum, these results can be considered perhaps the strongest evidence to date of (positive) correlation between spectral index and solar (sunspot) cycle.

Figure 3 presents the spectral index vs SEP. Although there appears to be a slight negative slope to the data, it is considered that this is not significant, *particularly* when considered in context of the (smaller) SEP data of Fig. 1, which in no way shows any continuation of such a trend (i.e., a spectral index (negative) correlation with SEP). When considered jointly, it is suggested that Figs. 1 and 3 provide little indication of any significant spectral index radial variation.

IV. Summary and Discussion

A new DSN capability has been utilized to obtain a sizeable volume of spectral index information during the Voyager 1978 solar conjunction. Major conclusions derived from a comparative study of these data with similar data obtained during 1976 solar conjunctions of Helios and Viking are:

(1) There has been a significant change in the spectral index from solar cycle minimum (1976; $K_0 = 2.42$) to (near) solar cycle maximum (1978; $K_0 = 2.67$).

(2) There continues to be evidence for a slight (positive) correlation between spectral index and solar (sunspot) cycle.

(3) There continues to be little or no evidence for a significant variation of spectral index with radial distance.

This new DSN capability is expected to be exercised in future years to derive spectral index information from Voyager solar conjunction Doppler phase fluctuation data, and hence to allow the continued monitoring of spectral index variations during the remainder of solar cycle 21.

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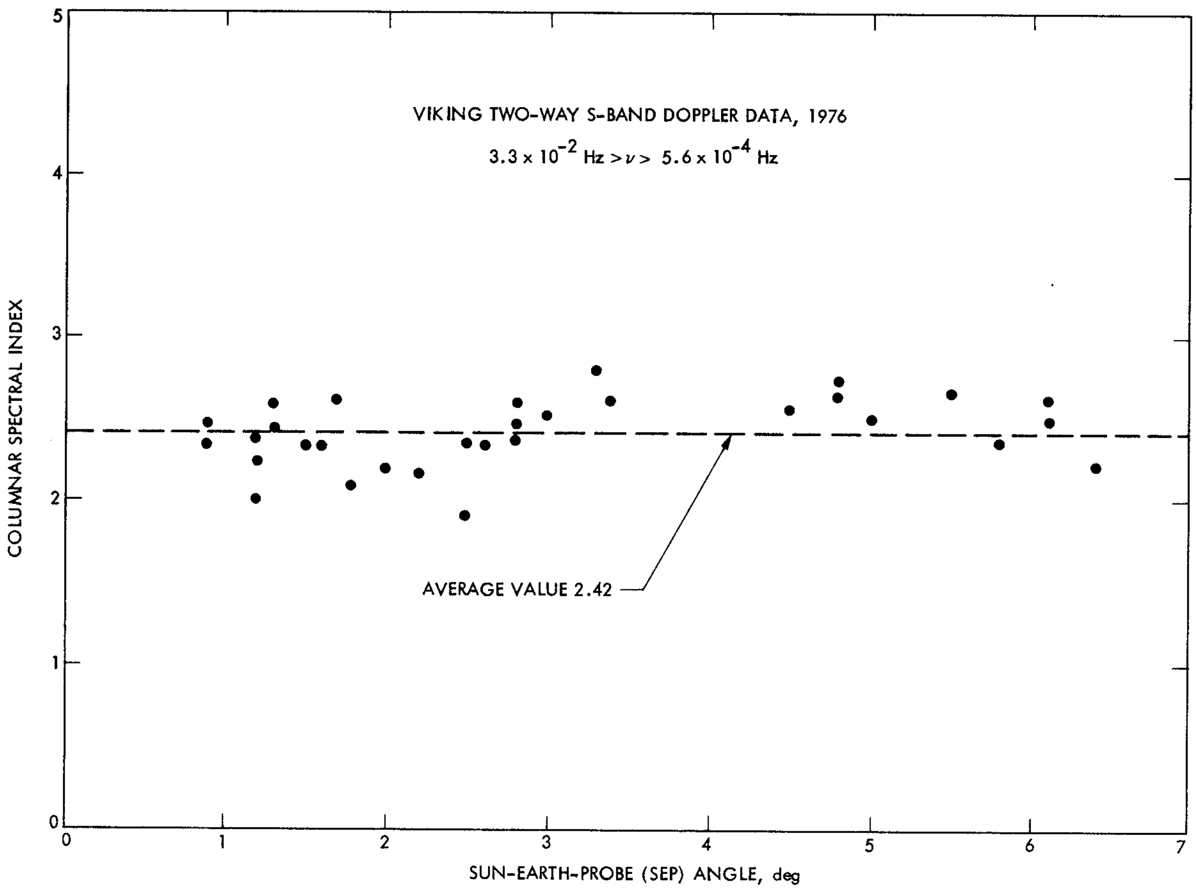

Fig. 1. Columnar solar wind phase fluctuation spectral index vs Sun-Earth-probe angle, 1976

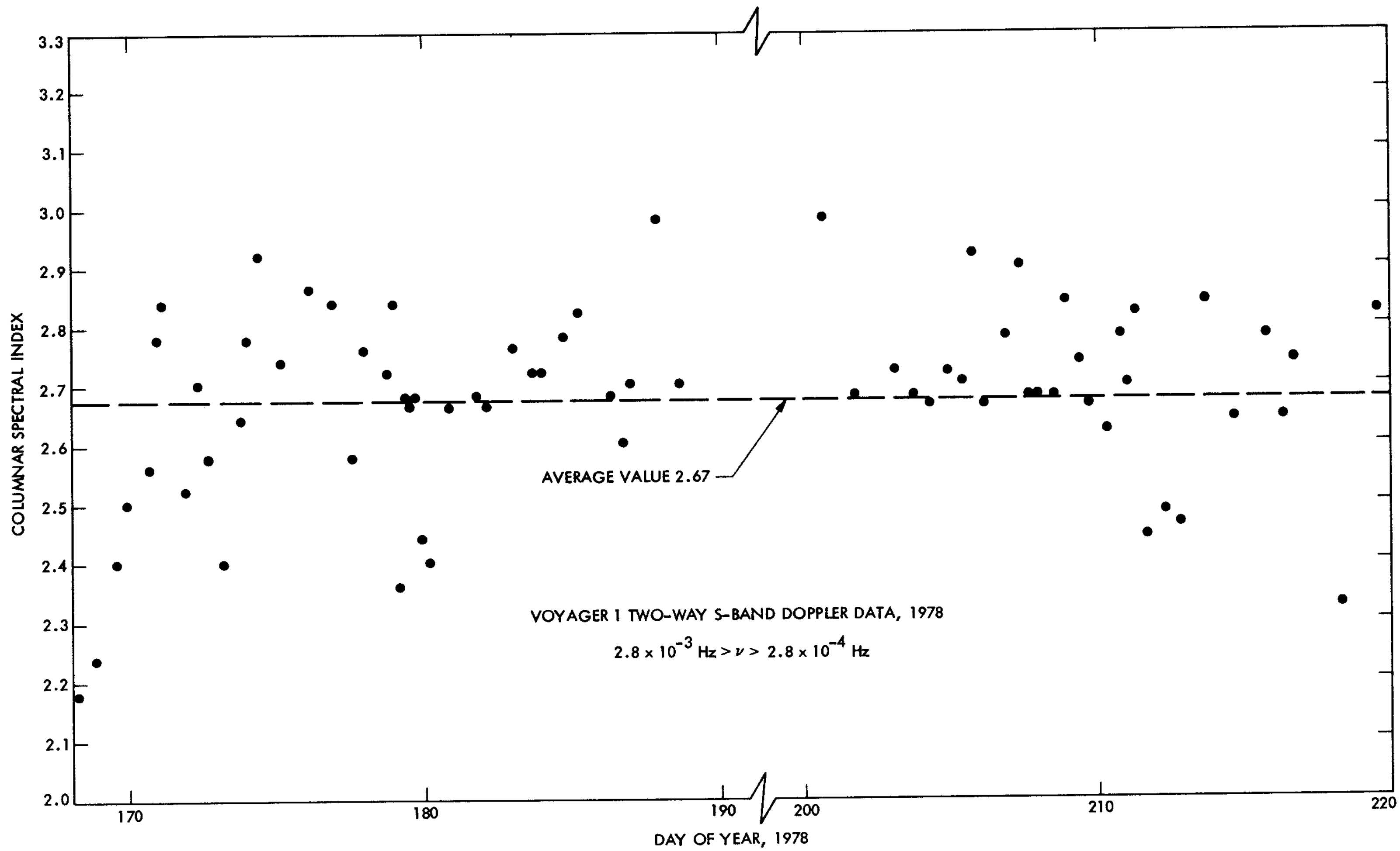

Fig. 2. Columnar solar wind phase fluctuation spectral index vs day of year, 1978

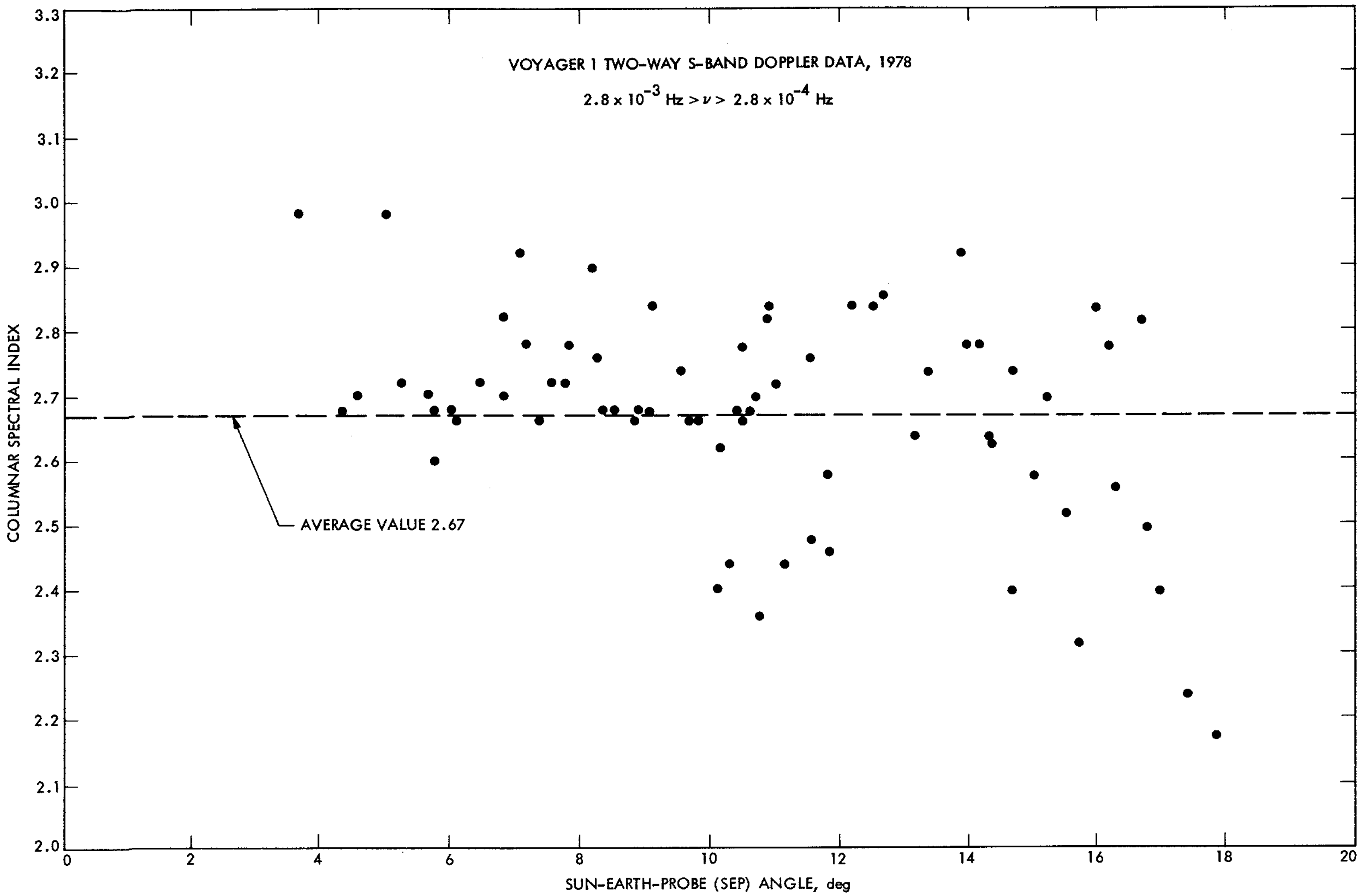

Fig. 3. Columnar solar wind phase fluctuation spectral index vs Sun-Earth-probe angle, 1978